Science & Technology REVIEW

March 2005

National Nuclear Security Administration's
Lawrence Livermore National Laboratory

Bridging Cultures to Enhance Security

Also in this issue:

- Tracing the Source of Nuclear Materials
- Experiments Bring Geophysics Indoors
- Gamma-Ray Bursts May Be Source of Common Elements

About the Cover

Cooperation on science and technology research offers opportunities for the U.S. to reduce tensions in critical regions of the world. As described in the article beginning on p. 4, Lawrence Livermore is participating in several of these collaborations, using the Laboratory's expertise in seismology and nuclear materials to address issues that cross national boundaries. For example, Livermore scientists are advisors to a project to protect Issyk-Kol, a large freshwater lake of economic importance to Kyrgyzstan. On the cover, Kyrgyz scientists work with a colleague from Germany to measure the radioactive contamination that remains in groundwater at Kaji-Say, the site of a Soviet-era uranium mining operation on the shores of Issyk-Kol. Behind the scientists, tile stars decorate the archway of an astronomy school built in the 15th century in Samarkand, Uzbekistan. The map in the background illustrates the importance of Central Asia to U.S. counterterrorism and nonproliferation efforts because the region shares borders with Afghanistan, Iran, Pakistan, Russia, and China. (*Map courtesy of the University of Texas Libraries, University of Texas at Austin*.)

Cover design: Kitty Madison; Photo credits: Richard Knapp

About the Review

Lawrence Livermore National Laboratory is operated by the University of California for the Department of Energy's National Nuclear Security Administration. At Livermore, we focus science and technology on ensuring our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published 10 times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

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National Nuclear Security Administration

Prepared by LLNL under Contract No. W-7405-Eng-48

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Lawrence
Livermore
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Contents

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S&TR, a Director's Office publication, is produced by the Technical Information Department under the direction of the Office of Policy, Planning, and Special Studies.

S&TR is available on the Web at www.llnl.gov/str.

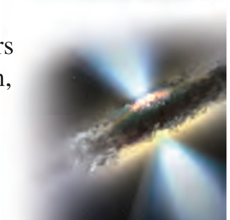
Printed in the United States of America

Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

UCRL-TR-52000-05-3
Distribution Category UC-99
March 2005

Features

Research Highlights



Departments

Activity discovered in gene deserts

A new roadmap to the location of DNA segments that are significant in medical, biological, and evolutionary research could emerge from recent studies by researchers from Lawrence Livermore and Lawrence Berkeley national laboratories, the Department of Energy's Joint Genome Institute (JGI), and Pennsylvania State University. These studies indicate that the so-called "gene deserts" in human and mouse DNA are teeming with activity. The trick for finding this activity is knowing where to look. Papers describing this collaborative research appeared in the January 2005 issue of *Genome Research*.

Gene deserts are long stretches of DNA between genes. Scientists originally believed gene deserts had no biological function and so dismissed them as "junk" DNA. However, recent studies indicate that many of these noncoding segments help regulate gene activity.

In the studies, researchers used computational tools to decipher gene regulation by examining the genomes of several species. When scientists compared the human genome with the recently sequenced chicken genome, they discovered that gene deserts actually fall into two distinct categories: those that remain relatively stable throughout eons of evolution, and those that undergo significant variation.

Results from this project indicate that the stable desert regions have an important regulatory role. These regions can resist genomic rearrangement and thus protect the complex operations of the flanking genes.

The variable regions, however, seem to be devoid of biological function. These regions make up about two-thirds of the gene deserts and as much as 20 percent of the entire three-billion-base-pair human genome. Results from the research collaboration indicate that a significant fraction of the genome may not be essential and, thus, is not likely to be involved in causing diseases.

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Biomolecules used to manipulate crystal shapes

Scientists from Lawrence Livermore and Virginia Polytechnic Institute and State University have studied how different biomolecules affect the dynamics of atomic steps during crystallization. In crystals, the flat surfaces forming crystalline faces are separated by steps, each of which is an atomic layer high. The team's results, which were published in the November 19, 2004, issue of *Science*, show that the classic theories of crystal growth merge smoothly with a two-decades-old model proposed to explain crystal-shape modification during bioremediation.

The research focused on calcite—a mineral with more than 300 identified crystal forms that can combine to produce at least a thousand different crystal variations—and calcium oxalate, the main component of kidney stones. When the team combined calcite with magnesium, the corners formed by the intersection of atomic steps flattened and roughened. As a result, the crystal's corners were flattened, and its shape was elongated and roughened. When calcite was combined with acidic amino acids, both the step and crystal shapes changed to reflect the handedness of the amino acids—that is, whether the molecule was right- or left-handed. Molecular simulations showed that the step edges provided the most favorable binding environment for the amino acids.

The team also conducted experiments combining calcium oxalate with citrate, a naturally occurring inhibitor and therapeutic agent for kidney stone disease, and calcite with a protein extracted from abalone nacre, a pearly substance that lines the interior of many shells. In both combinations, the changes occurred at specific atomic steps and directly determined the shape of the macroscopic crystals.

This research shows that, although biomolecules generate modified crystal shapes with new faces, shape is controlled by step-specific interactions between growth modifiers and individual step edges on preexisting crystal faces.

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Livermore opens the Microarray Center

In December 2004, the Livermore Microarray Center (LMAC) opened to provide Laboratory scientists with the latest microarray equipment and expertise to support their genetic research. Microarrays, also known as biochips or gene chips, are a powerful tool that researchers can use to determine which genes in a cell are active, or expressed, under differing conditions, what their level of expression is, and how they interact with each other.

The center combines all of Livermore's microarray resources and expertise in a central facility that can be used to serve researchers in a laboratory environment. Using LMAC's services and expertise in statistical analysis, Laboratory scientists will be able to analyze and compare the activity of thousands of genes at a time—furthering their research in such areas as cell response to radiation exposure, the causes of cancer and other diseases, and the genetic makeup of the bacteria that cause plague and anthrax.

Microarrays are small glass, nylon, or silicon slides on which robots place, or "print," tiny amounts of DNA in a regular pattern. Each spot features short, immobilized DNA segments called oligonucleotides of a given sequence. One slide can have up to 30,000 unique spots, representing hundreds to thousands of different gene sequences.

Fluorescently labeled nucleotide strands representing genes from the cell under study are allowed to bind, or hybridize, to their matching counterparts, which are immobilized on the slide. By measuring the brightness of each fluorescent spot, researchers can determine how much of a specific DNA fragment is present and how active it is in the cell. Additional information on LMAC is available at microarray.llnl.gov.

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Enhanced National Security through International Research Collaborations

NATIONAL security today requires broad and effective engagement in the international arena. Many forums are available for such interaction, including formal participation in the United Nations and the International Atomic Energy Agency (IAEA), diplomatic interchanges with other countries, collaborative work with Russia to secure Soviet-legacy nuclear materials, and even science and technology collaborations with regions or countries of strategic concern to the U.S.

Myriad drivers push countries to acquire weapons of mass destruction (WMD), and many countries where proliferation or terrorism is of concern to the U.S. are located in regions of long-standing instability or political tensions, such as the Middle East, Central and South Asia, and the Caucasus. A difficult but important challenge in these regions is to establish avenues of communication between adversaries.

As we found when the first U.S.–Russia lab-to-lab interchanges were started, science and technology cooperation is an effective way to establish trust and respect. From these initial efforts has grown a $1-billion-per-year suite of collaborative U.S.–Russian activities in nuclear material protection, fissile material disposition, counter-nuclear smuggling, and weapons complex downsizing. These activities form the critical “front end” of this nation’s nonproliferation strategy.

Similarly, it is in this nation’s best interests to help defuse the tensions that destabilize regions and contribute to countries’ motivations to acquire WMD. As with Russia, science and technology cooperation is offering opportunities toward this end, and Lawrence Livermore is a key participant in these efforts. We are leveraging our acknowledged expertise in seismology and nuclear materials to address transboundary issues of critical importance to these regions of concern. As described in the article beginning on p. 4, we are using collaborative projects on seismic safety and water resources to bring together scientists and government officials from these regions to share data, conduct joint analyses, and develop mutual response plans.

For example, Kyrgyzstan, Uzbekistan, and Tajikistan inherited a problematic radioactive legacy from the Soviet Union—uranium mine tailings that threaten to contaminate one of the region’s main water sources and its prime agricultural resource. This region is a historically unstable and densely populated area, with high unemployment and increasing religious extremism. The Laboratory has cosponsored workshops to assess the situation and collaborated with regional experts to propose methods for securing the mine tailings and preventing catastrophic contamination. Livermore researchers are also working with large international donors to execute those plans. One remarkable achievement has been the adoption of the Laboratory’s approach by the regional and international community and its application to other Soviet uranium legacy issues in Central Asia.

Other activities are under way in the Middle East and North Africa, using cooperation in seismology and WMD terrorism prevention as a means of opening dialogue and building trust among scientists and decision makers from long-standing adversarial countries. Most recently, following Libya’s December 2003 renunciation of its WMD programs, Livermore scientists began participating in international cooperative efforts to redirect Libyan scientists to peaceful uses of their scientific and technological expertise. Livermore is also working with the IAEA to help ensure the safe and secure operation of Libya’s research reactor.

This somewhat unconventional application of the Laboratory’s science and technology capabilities in the international arena has successfully built alliances and cooperation where few previously existed. Bit by bit, these projects help reduce regional tensions, thus addressing one root cause of proliferation and terrorism. They also help to enhance our nation’s influence in critical regions of the world. By serving as a neutral interface among the scientific and policy communities, foreign and domestic organizations, and people from different countries and of diverse social status, Lawrence Livermore is making significant contributions to regional, global, and national security.

■ Stephen G. Cochran is acting associate director of Nonproliferation, Arms Control, and International Security and acting director of the Homeland Security Organization.

Building Networks of Trust through Collaborative Science

Livermore researchers are spearheading projects with foreign colleagues to help bridge cultural differences and strengthen regional security, trust, and scientific expertise.

PROGRESS in science and technology is readily acknowledged for dramatically improving human health and increasing standards of living. However, science and technology can also serve as powerful tools for advancing regional security and building a network of trust among nations. Lawrence Livermore scientists are using science- and technology-based cooperative projects as a means of helping foreign colleagues work together to curb nuclear smuggling, understand earthquake hazards, prepare for disasters, and prevent massive environmental damage.

"We want to foster communication among scientists in two regions that are of particular concern for nuclear proliferation—Central Asia and the Middle East," says Jay Zucca, a leader in Livermore's Proliferation and Terrorism Prevention Program, which is part of the Nonproliferation, Arms Control, and International Security (NAI) Directorate. "Science and technology can build bridges between nations and cultures while serving the societies in them." By engaging scientists in young or unstable nations or troubled regions, these collaborations can help foster openness, make the region more attractive to outside investment, prevent the proliferation of weapons of mass destruction (WMD), and reduce the influence of terrorist groups.

Livermore-led collaborative projects are supported by U.S. and European government agencies, the United Nations, the World Bank, and private organizations. The projects bring together scientists in a geographic region to work on high-priority technical issues that cross national boundaries. In many cases, the projects are the first time scientists from the different nations have worked together. About a dozen employees from Livermore's NAI, Chemistry and Materials Science, and Energy and Environment directorates participate in the collaborations. The

A village elder (back to camera) discusses water needs with (from left) Livermore scientists Jeff Richardson and Andy Tompson and an interpreter. The group is standing over a well that supplies briny water. In the background (upper left, p. 4), a cistern holds the village's water, which is currently supplied by truck.

majority of work is done by regional participants, thereby strengthening the area's science and technology.

Geophysicist Richard Knapp, who heads Livermore's work in Central Asia, notes that U.S. preeminence in science and technology is highly regarded in the region. Because of this widespread admiration, American scientists can assist U.S. policy goals in Central Asia and the Middle East by helping to bridge cultural differences, thereby easing regional tensions.

Knapp notes that projects headed by Livermore employees earn high marks from the collaborators because Laboratory scientists are experts in their fields and are interested in true collaboration. "We don't just bring knowledge," he says. "We ask questions, listen, show respect, and work with them as partners."

Central Asia Pivotal

Many projects are sited in Central Asia. Funding comes from the U.S. departments of State, Defense, and Energy, and partners include the World Bank, the Organization for Security and Co-operation in Europe (OSCE), and the International Atomic Energy Agency. Many Central Asian science institutes and government agencies also participate in these collaborations.

Central Asia is a region of 60 million people. Throughout history, it has served as a center for transporting goods between Europe and Russia to the north, the Middle East and South Asia to the south, and China to the east (where the ancient Silk Road is one of the world's oldest trade routes). The region remains a nexus through which illicit trade in drugs, conventional arms, and potentially WMD can flow. Since the terrorist attacks of September 11, 2001, Central Asia has become particularly important to U.S. counterterrorism and nonproliferation efforts because it shares borders with Afghanistan, Iran, Pakistan, Russia, and China.

Central Asia is important to U.S. counterterrorism and nonproliferation objectives because the region shares borders with Afghanistan, Iran, Pakistan, Russia, and China. (*Courtesy of the University of Texas Libraries, University of Texas at Austin.*)

Central Asian nations generally have developing economies, uncertain internal stabilities, and poor relations with each other. Political instabilities in this area could lead to conflicts involving militant factions, proliferation of WMD, and civil war. "Afghanistan is an example of a state that was failing," says Livermore geochemist Nina Rosenberg. "It shows that we can't afford to ignore the nations of Central Asia."

Livermore's objectives in Central Asia are to help reduce the flow of illicit nuclear materials, enhance regional stability, and build regional technical cooperation. "Through our work, we helped lay a foundation of respect and trust across the region," says Rosenberg. She notes that although the region's science and technology infrastructure has suffered since these nations gained their independence more than a decade ago, scientists are still influential at high levels of government.

Detecting Nuclear Materials

Laboratory researchers have been working with Uzbekistan because of its central location. For example, they are providing the technology and training needed so Uzbek personnel can prevent the smuggling of nuclear materials and people across its borders. Since 1998, the Uzbekistan Customs Services, Border Guards, Institute of Nuclear Physics, and Ministry of Defense have collaborated with a Livermore team to install an integrated, national system of radiation portal monitors at the international ports of entry. In addition to Knapp, the project team includes Jeff Richardson, who leads Livermore's Proliferation and Terrorism Prevention Program, and scientists Arden Dougan, Dave Herr, and Stan Erikson. The project is supported by the U.S. Defense Threat Reduction Agency's (DTRA's) Weapons of Mass Destruction Proliferation Prevention Initiative.

The Livermore and Uzbek team prioritized the Uzbek ports of entry and installed pilot monitoring systems in four high-priority international ports of entry: those on the borders with Kazakhstan, Afghanistan, and Turkmenistan and one at the Tashkent International Airport. The team also trained Uzbek customs personnel on using this equipment to detect nuclear smuggling. The portal monitors detect gamma and neutron radiation from shipping containers, vehicles, and objects carried by pedestrians. Radiation levels exceeding a set threshold activate an alarm. The portal monitors also provide continuous video surveillance. Officials at the national Uzbek command center can check the status of every detector and follow any incident over video monitors.

Using the pilot systems, Uzbek officials intercepted two illicit shipments of radiological materials. With funding from DTRA, the project is expanding to include all 41 ports of entry. Other Central Asian nations are considering nuclear detection systems similar to those in Uzbekistan. Detectors are also being installed in Russia and Kazakhstan under a Department of Energy– (DOE-) funded program called the Second Line of Defense.

The U.S. Central Command (CENTCOM) is an important Department of Defense partner in Central Asia and provides funding for Livermore's work in the region. Since 2001, Rosenberg and Knapp have provided technical advice, given talks, and cochaired panels at CENTCOM's annual Central Asia States conferences. At a recent conference, participants discussed applying technical expertise and equipment for monitoring WMD materials to prevent cross-border trafficking in drugs, terrorists, and conventional weapons. Conference participants also considered different approaches to integrate WMD experts more fully into civilian research and teaching at universities.

Preventing Environmental Disasters

One common concern for the nations in Central Asia is threats from environmental disasters that could potentially affect regional stability. For example, during the Soviet era, this region was an important source of uranium ore. Uranium mine tailings—the radioactive and toxic waste from past mining operations—are common throughout the region and threaten human health and the environment. The threat is especially acute in the Fergana Valley, a region that includes significant parts of Kyrgyzstan, Uzbekistan, and Tajikistan. The Fergana Valley is a politically unstable area and has been a center of Islamic extremism. The area is densely populated, and unemployment is high, which further contribute to the instability.

The former Soviet uranium mining site at Mailuu-Suu in Kyrgyzstan, near the Uzbekistan border, has the highest priority.

A Livermore team has been working with Uzbek officials to install an integrated, national system of radiation portal monitors at international ports of entry. (a) Vitaliy Petrenko, from Uzbekistan's Institute of Nuclear Physics, walks by a pedestrian radiation portal monitor at the Gisht-Kuprik port of entry, which is just north of Tashkent on the border with Kazakhstan. (b) A truck leaving Uzbekistan drives by a radiation portal monitor at the Alat port of entry, which is on the border with Turkmenistan and is a major route to Iran.

The site includes 23 impoundments of radioactive debris that are precariously poised on the banks of the Mailuu-Suu River. The area is prone to huge landslides, and a landslide involving the tailing wastes could threaten the health and livelihoods of millions of people in three nations.

Rosenberg helped create a database of historical information to support rehabilitation efforts at Mailuu-Suu. A series of workshops in 2003 was cosponsored by Kyrgyzstan, OSCE, and Lawrence Livermore. The workshops were attended by senior government and technical officials from Kyrgyzstan, Tajikistan, Uzbekistan, Kazakhstan, Russia, Germany, and the U.S. and from international organizations. One attendee was from the Ministry for Atomic Energy of the Russian Federation. Says Knapp, "For the first time, the ministry opened its Cold War files about Mailuu-Suu."

A workshop in October 2003 in Bishkek, Kyrgyzstan, pioneered a new climate of cooperation. During the workshop, the Bishkek Declaration was signed by regional and international representatives promising to cooperate on common uranium legacy issues. The declaration also created a steering committee, of which Knapp is a founding member. The Laboratory's efforts helped bring about a $12-million grant from the World Bank and other organizations to increase the safety of the Mailuu-Suu uranium tailings.

The steering committee met again in September 2004 in conjunction with a workshop on "The Fergana Valley: Key Technical Legacy Issues," which was sponsored by Livermore (with DOE funding) and the Embassy of the Republic of Uzbekistan in Washington, DC. The committee met with regional ambassadors and U.S. government agency representatives, who agreed that the uranium legacy issues in Tajikistan posed a great threat to the Fergana Valley. As a result,

This uranium mill tailings impoundment at Mailuu-Suu, Kyrgyzstan, on the banks of the Mailuu-Suu River, is one of 23 such impoundments in the Mailuu-Suu Canyon. The canyon is prone to massive landslides (in background), and the river flows into the Fergana Valley, about 25 kilometers downstream.

the World Bank is considering expanding its program at Mailuu-Suu to Tajikistan, with Livermore help.

Expanding Efforts

Livermore leads another Soviet legacy project, Kaji-Say, a uranium tailings impoundment on the shores of Issyk-Kol, a large freshwater lake of great economic and spiritual importance to Kyrgyzstan. Livermore experts are advisors to a project, funded by the State Department through DOE, to protect the lake from radioactive contamination. The project is also designed to demonstrate the technical expertise of Kyrgyz scientists and help them develop Western-style project management skills.

In addition, Livermore has a partnership with Kazatomprom, the Kazakhstan national company that supplies uranium fuel to nuclear power plants in Europe and Asia. Laboratory hydrologist Andy Tompson is advising environmental managers at the Ulba Metallurgical Plant, which was once part of the Soviet nuclear weapons complex but, since 1997, has been part of Kazatomprom. The plant stores nuclear and beryllium wastes in slurry form in lined ponds. In 2004, a team of chemists from Kazatomprom visited the Laboratory to confer on computer techniques for modeling the waste situation and to study Livermore's pump-and-treat methods of cleaning contaminated groundwater.

Tompson is also advising scientists studying the migration of radionuclides that remain after decades of nuclear tests at Semipalatinsk, the former Soviet test center in Kazakhstan. "We share our experiences about studying similar nuclear transport issues at DOE's Nevada Test Site and at the proposed Yucca Mountain nuclear waste site," says Tompson. "We also learn from their experiences."

No Boundaries for Seismic Activity

Central Asia is among the most seismically active regions on Earth. In the last 50 years, the region has suffered several devastating and economically debilitating earthquakes. Livermore seismologist Eileen Vergino says, "The political, economic, and life disruptions and damage caused by earthquakes are of grave concern for this region."

To help address those threats, Livermore scientists are participating in the Central Asia Seismic Risk Initiative (CASRI). The initiative's focus is assessing seismic hazards and mitigating risks in Central Asia through scientific cooperation. CASRI is modeled after the highly successful Caucasus Seismic Information Network project, of which Livermore is a partner. Says Vergino, "Through CASRI, we are expanding the cooperative work we are doing in the Caucasus to Central Asia."

CASRI's goal is to have regional scientists share seismic, geologic, and geophysical data and develop regional hazards models. The scientists will use these models to advise their governments on the best ways to mitigate the effects of a damaging earthquake. Another key goal is to help educate a new generation of seismic experts in the area.

The Middle East and Arabian Gulf are the focus of cooperative seismology projects that promote understanding among regional nations, including Israel. A strong collaboration between Livermore and the U.S. Geological Survey (USGS) makes possible conferences, data exchanges, and seismic tests and helps strengthen national seismic networks. The results include improved assessment of earthquake hazards, revised building codes, and better construction methods. The U.S. also obtains data for improved seismic models to support its goals in monitoring compliance with nuclear arms agreements.

Livermore seismologist Keith Nakanishi points out that seismology is inherently an international science because seismic waves

This dinner was hosted by the Kyrgyzstan Minister of Ecology and Emergencies to celebrate the signing of the Bishkek Declaration in October 2003. The dinner was attended by the Tajikistan Minister of Industry, ministerial representatives from Uzbekistan and Kazakhstan, and technical representatives from Russia, Germany, Kyrgyzstan, and Lawrence Livermore.

do not stop at political boundaries. As a result, he says, “Concern about seismic hazards catalyzes regional cooperation.”

Cooperation between countries is crucial in better defining the effects of earthquakes and in determining an area’s geologic structure. By measuring seismic waves and studying those data, scientists can determine the earthquake mechanism that generated the seismic signals, the location of the earthquake, and the physical properties of the geologic media through which the waves pass. This information can be used to mitigate the effects of damaging earthquakes, better define the location of subsurface faults, and recognize areas that are prone to earthquake damage.

Nakanishi says that in the Arabian Gulf region, Saudi Arabia, Kuwait, and Oman have high-quality seismic networks, but other nations have sparse networks—or none at all—and do not share data. Livermore is helping build a virtual regional data network that combines national technical resources so seismic researchers can electronically share data following an earthquake.

Meetings are held in the eastern Mediterranean region under United Nations sponsorship and are open to all regional participants, including Israel, Arab nations, Turkey, Cyprus, and Iran. Topics include group analysis of seismic data and discussions of mitigating effects from damaging earthquakes. (See *S&TR*, March 2000, pp. 21–23.)

Livermore seismologist Arthur Rodgers checks on a seismic station erected at Al Hayl, United Arab Emirates, as part of a joint project between the Laboratory and United Arab Emirates University. The enclosure contains seismic equipment powered by the solar cell to the left.

Working with United Arab Emirates

Two earthquakes and many aftershocks struck the northern part of the United Arab Emirates (UAE) in early 2002. Because no national seismic network exists, no local seismic data were recorded. In May 2003, a Livermore team led by Arthur Rodgers deployed two Livermore seismic stations in the UAE as part of a joint research project on seismology with the United Arab Emirates University. Data collected by these stations are helping scientists at the university and Livermore to understand the Earth’s crust in the northern Emirates. “We hope this effort will be the first step toward developing seismologic expertise in the UAE and forming a foundation for a national seismic network,” says Nakanishi.

Livermore, the USGS, and the University of Sharjah in the UAE organized the first Gulf Seismic Forum, which was held at the university in February 2004. More than 90 participants attended from throughout the region, Canada, South Africa, Switzerland, Turkey, the United Kingdom, and the U.S.

Trips to Oman and Qatar have led to a potential expansion of seismic cooperation in the Gulf region. While Oman has a modern seismic network, Qatar has only a small network and little analysis capability. However, Qatar is important in monitoring seismicity in the Gulf region. Livermore is therefore proposing to work with Qatar on advanced data processing procedures.

Livermore researchers are also helping Iraq to rejoin the regional seismic community. “Iraq has a long tradition in seismology, and Iraqi seismologists are well trained,” says Nakanishi. The nation installed and operated the first seismic network in the Arab world. Three stations are still in operation. Livermore is collaborating with the Earthquake Center at the University of Arkansas at Little Rock to preserve Iraqi seismic data recorded during the past 20 years.

In addition to the work on earthquakes, Livermore is collaborating with the Gulf

Cooperation Council (GCC) nations of Qatar, UAE, and Kuwait to enhance the council's ability to respond to an act of terrorism involving WMD. This project, which has funding from DOE's National Nuclear Security Administration, assesses current GCC national and regional capabilities and evaluates personnel training. As part of this effort, Livermore scientists from the National Atmospheric Release Advisory Center are working with the GCC to plan responses to different scenarios involving WMD and to train personnel as emergency responders. The Laboratory hosted a workshop on radiological emergencies for Qatar experts in December 2004. Livermore experts are also working with colleagues in Dubai on techniques to detect WMD smuggling through its ports.

The Common Problem of Water

Water issues are common to every nation in the Middle East and Arabian Gulf. "Water problems are acute and are transboundary," says Tompson. "Supplies are not adequate for the large and growing populations of the area." In addition, water issues can be complex and invite distrust among nations.

Middle East water experts have attended Livermore-sponsored workshops in Amman, Jordan, and in Livermore. Tompson says it is especially gratifying to see Israeli, Jordanian, and Palestinian scientists working together. "The name of the game is building relationships," says Tompson. "It's the foundation for everything we do."

Tompson participated in an effort to test a solar-powered, portable desalinization unit that would improve the quality of water supplies in Middle Eastern villages. Many village wells are salty either because they are close to the ocean or because of the geochemical nature of the aquifer. Water treated by portable desalinization devices could be stored in cisterns and the neighboring villages could share the equipment.

Livermore experts are collaborating with a group of Israeli and Palestinian scientists who are studying water taken from the Jordan River. "The goal in this project is to understand how groundwater and surface water are interacting," says Tompson. "For example, if I drill a well near the Jordan River, am I lowering the river's water level?"

Tompson, in collaboration with the Jordanian Ministry of Water and Irrigation, Jordan University of Science and Technology, and the Royal Society for Conservation of Nature, has visited Jordan many times since 1998 to help people understand the workings of groundwater. One focus of his visits is Jordan's Azraq Basin. A well-known oasis is located at the basin's topological low point and, thus, has traditionally enjoyed high groundwater levels, springs, and verdant wetlands. However, the increased drilling of water wells in the basin is starting to dry up the oasis. A Livermore team built tabletop models to illustrate how groundwater levels and well drilling are interconnected. These models were copied by the Jordanians and are now being used by students and government agencies.

With Livermore support, a Jordanian college student working on her master's degree developed a simplified version of a Livermore supercomputer program that simulates groundwater movement. The

Dignitaries at the opening session of the Gulf Seismic Forum included Sheikh Sultan bin Mohammed bin Sultan Al Qasimi (center front, in gold robes), the Crown Prince and Deputy Ruler of Sharjah, United Arab Emirates; Major General Mohammed Salim Kardous Al Amri (on the Crown Prince's right, in uniform), director general of the Directorate of Civil Defence at the Ministry of Interior; and Ismail Al Bishri (on the Crown Prince's left), the chancellor of the University of Sharjah. At the far right is Livermore seismologist Arthur Rodgers.

student is currently a Fulbright scholar at the University of California at Berkeley, where she is obtaining a Ph.D. in civil engineering with a specialty in hydrology.

The Laboratory may extend this water effort to Syria. Tompson has met with representatives from the Syrian ministries of education, irrigation, and environment and two Syrian universities to plan future visits and collaborative work. In September 2004, Tompson was one of the first American scientists to visit Libya following the cessation of an international boycott. Under DOE and State Department sponsorship, he attended a workshop on water issues and nuclear medicine.

The seismic and hydrologic work in the Middle East has established a foundation for other Laboratory efforts. For example, Livermore researchers are working with countries on the Arabian Gulf to address various issues related to radiologic emergencies.

Cooperation in South Asia

Livermore seismic experts are having success in fostering cooperation among South Asian nations. The area has many earthquakes, numerous seismic stations, and good expertise in seismology. Regional meetings, which included participants from both India's and Pakistan's atomic research centers, resulted in agreements for nations to share seismic fault data and to jointly process data from earthquakes that occur along borders.

In October 2003, Livermore researchers participated in a South Asian seismic workshop in Colombo, Sri Lanka, which included participants from China, Iran, Afghanistan, Pakistan, India, Nepal, Bangladesh, and Sri Lanka. Another meeting was held in Bangladesh in September 2004. These meetings focused on collaborative research in mapping earthquake faults and determining earthquake locations along border regions.

"We want to help these nations build a regional seismic fault map," says Nakanishi. "Earthquakes that occur on or near national borders are a particular problem because the stations in one country do not adequately cover the area involved. Data from neighboring countries

Livermore hydrologist Andy Tompson demonstrates to Jordanian students how the water table is affected when wells are drilled.

is needed to give a complete picture of seismic activity. We can't fully understand a region's seismicity if nations don't share seismic data." Yet too often, seismic data are withheld as if they were classified information.

The Sumatra earthquake on December 26, 2004, and the resulting tsunami emphasize the importance of sharing seismic data. Even relatively aseismic countries such as Sri Lanka are vulnerable to the devastating effects from earthquakes. An efficient system that allows countries in the region to exchange data and quickly release warnings to at-risk populations might mitigate some of the danger. Fostering the exchange of information is an important goal of regional cooperation.

Enhanced Stability, More Trust

Knapp notes that nongovernmental agencies are helping to advance regional stability and improve the networks of trust. The ways in which U.S. policy goals in Central Asia can be strengthened through science and technology were discussed at a February 2003 workshop, which was sponsored by the American Association for the Advancement of Science and Livermore's Center for Global Security Research.

Livermore is also partnering with the Brookings Institution to foster and promote science and technology cooperation between the U.S. and Islamic nations. An Islamic Forum, organized by Brookings and cosponsored by Livermore, is scheduled to take place this month in Doha, Qatar. A follow-on meeting, the Samarkand Dialogues, will be held later this year at the site of a 15th-century observatory in Uzbekistan, and participants are expected from 10 Islamic nations. The forum's theme is how science and technology can bridge the Western and Islamic worlds.

"Livermore researchers are developing networks of trust," says Knapp. Increased trust through science and technology collaborations benefits the U.S. by reducing regional stress, which might otherwise lead to conditions that promote terrorism or WMD proliferation. As a result, nations enjoy enhanced levels of security, standards of living, and scientific and technological expertise.

—Arnie Heller

Key Words: Central Asia, Central Asia Seismic Risk Initiative (CASRI), Defense Threat Reduction Agency (DTRA), earthquakes, Middle East, seismology, South Asia, United Arab Emirates (UAE), uranium processing, U.S. Central Command (CENTCOM), water issues, weapons of mass destruction (WMD).

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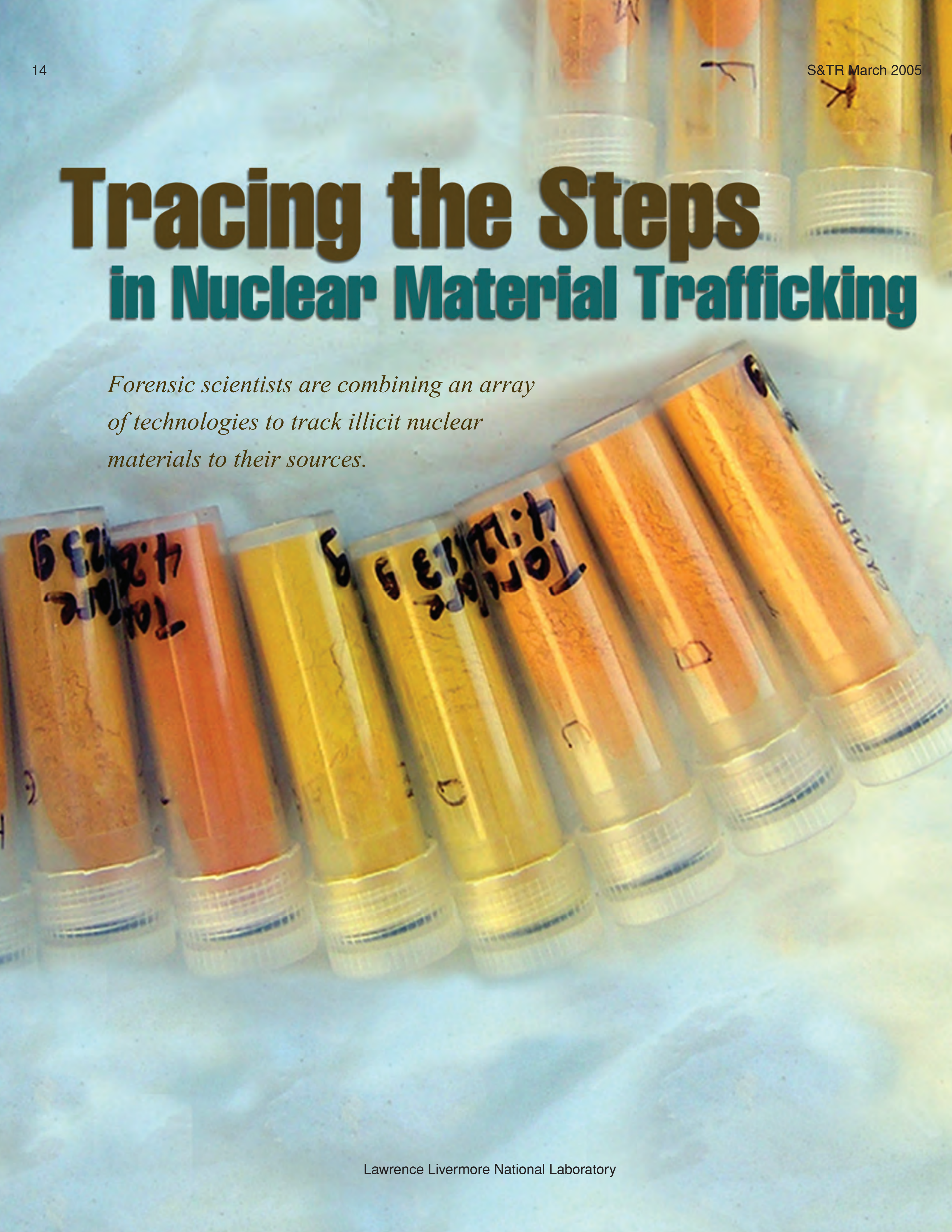
The mountains south of Bishkek, Kyrgyzstan.

Lawrence Livermore National Laboratory

Tracing the Steps in Nuclear Material Trafficking

Forensic scientists are combining an array of technologies to track illicit nuclear materials to their sources.



THE nuclear threat during the Cold War came from known adversaries, and a great concern for U.S. national security was that countries possessing a nuclear arsenal might use these weapons in a time of international crisis or by accident. The collapse of the Soviet Union and the increase in terrorism have given rise to new threats and adversaries. Today, the U.S. must prevent terrorists from acquiring not only nuclear weapons but also the materials that can be used to make such weapons, including fuel for nuclear power plants and radioactive materials intended for medical use.

In the last 10 years, a new research area called nuclear forensic analysis has emerged to address this growing concern. As part of the Laboratory's national security mission, researchers are assisting in an international effort to develop new methods to thwart illicit trafficking of nuclear materials.

Nuclear forensic science involves more than determining the physical and chemical characteristics of the nuclear material. Livermore physicist Ian Hutcheon, who serves as chief scientist for the Laboratory's nuclear forensic team, explains, "The goal is to identify as many clues in intercepted nuclear and radiological samples as possible. These so-called attribution indicators provide us not only with a characterization of the nuclear material, but also with environmental links that could help us trace the path the material took from its point of origin or determine how recently it passed from legitimate to illicit use."

Nuclear materials can be placed into one of three general categories: special nuclear material (SNM), reactor fuel, and commercial radioactive sources. SNM includes the basic building blocks of nuclear weapons: weapons-grade plutonium and highly enriched uranium (HEU). Reactor fuel includes low-enriched uranium (LEU), reactor- and fuel-grade plutonium, and mixed oxide– (MOX-) grade plutonium. (MOX fuel is a mixture of plutonium and depleted uranium oxides and can be a substitute for LEU.) Commercial radioactive sources are used in medical diagnostics, thermoelectric generators, food irradiators, and radiography equipment.

SNM is attractive to terrorists because, in sufficient quantities, it eliminates the need to enrich uranium or acquire plutonium. However, nations with nuclear weapon capabilities protect their HEU and plutonium stockpiles with extensive security systems. Reactor fuel cannot be directly used to build a nuclear device, but it is stored in many locations throughout the world and tends not to be as rigorously secured. Terrorists might try to acquire reactor fuel and other radioactive materials to construct a radiological dispersal device, or dirty bomb.

Livermore's Nuclear Forensic Roots

Nuclear forensic work at the Laboratory began in the late 1980s as an outgrowth of the nuclear test program. To analyze underground nuclear experiments, researchers mixed chemical and isotopic tracers with the nuclear test device and measured the isotopic composition of the debris produced during the experiment. These data would help scientists determine the device's yield and provide important feedback to the design team.

Livermore nuclear chemist Ken Moody believed trace radionuclides could be used in a similar fashion to determine the origin of a nuclear material. Radioactive atoms decay at a rate determined by the amount of the isotope in the material and the half-life of the parent isotope. For example, thorium-230 is a decay product, or daughter isotope, of uranium-234, and uranium-235 is a daughter of plutonium-239. Therefore, by measuring the relative amounts of decay products and the parent isotope, scientists can establish a material's age—the time since the parent isotope was last chemically separated from its decay products.

Moody explains, "If a sample is completely purified, every one of the daughters should have the same age. If they do not, the difference indicates that the material has been altered or been through chemical processing. Because each manufacturer has different processing methods, we can use the age and other isotopic information to help identify, or attribute, where a sample was manufactured."

Livermore physicist Sid Niemeyer submitted a proposal to the Department of Energy (DOE) for the Laboratory to conduct further research on these age-dating techniques. DOE then assigned Lawrence Livermore with responsibility for leading the national laboratory effort in nuclear forensic analyses. In 2003, recognizing Livermore's technical expertise in nuclear forensic science, the Department of Homeland Security (DHS) selected the Laboratory to lead a new national program in nuclear attribution of undetonated materials.

Incidents of illegal trafficking in nuclear materials are not new. A DOE database lists worldwide cases from as early as 1966. However, until recently, these cases were usually frauds—that is, attempts by individuals to sell substances they claimed were nuclear material. Since 1991, the number of reported nuclear smuggling cases has risen, with approximately one seizure per month. Most of the seizures have involved small amounts of nuclear material produced in commercial nuclear reactors.

Many of the techniques used in traditional criminalistics are also useful for nuclear forensic analysis, such as microscopic analyses of fibers and packaging materials. However, in nuclear forensic analysis, radioactive elements are being analyzed, so the procedure used depends on the type of sample and its radioactivity. Forensic scientists must determine, for example, whether a sample is emitting large amounts of alpha particles or gamma rays; whether it is plutonium or uranium; or whether it is a solid, mixed powder, or liquid. Therefore, Livermore's nuclear forensic team uses a tiered approach in which the results from one analysis guide the team in selecting subsequent analyses.

Identifying the Nuclear Material

Every radioactive sample that arrives at the Laboratory's Forensic Science Center (FSC) is first screened for alpha particles and gamma rays. (See *S&TR*, May 2003, pp. 4–11; April 2002, pp. 11–18.) If a substantial amount of either is emitted, the sample is analyzed using sensitive spectrometers designed to measure those particles. Once researchers identify the material, they analyze its chemical and isotopic composition, which includes measuring the amount of major and trace elements in the sample, evaluating its physical structure, and in particular, determining the ratio of radioactive parent isotopes to daughter isotopes.

Livermore forensic scientists pioneered the use of this tiered approach, in which nondestructive techniques such as optical and scanning electron microscopy, Fourier-transform infrared (FTIR) spectrometry, and x-ray fluorescence (XRF) are first applied to determine a sample's overall composition and structure. The complete characterization of a sample by radiochemical and mass spectrometric analysis involves dissolution or vaporization, which destroys the sample. Therefore, these techniques are the final steps in the forensic process.

Livermore researchers work with other DOE national laboratories in forensic investigations, including Los Alamos, Oak Ridge, Pacific Northwest, and Savannah River national laboratories. Typically, Livermore performs a preliminary analysis of a nuclear sample. Then a second confirming analysis is made to ensure accuracy. Oak Ridge conducts this second analysis if the sample is uranium, and Los Alamos performs the analysis if the sample is plutonium. Oak Ridge also lends its expertise in x-ray diffraction, and Pacific Northwest and Savannah River provide expertise in nuclear reactor design and fuel reprocessing.

Because the nuclear forensic field is new and has relatively few experts, countries engaged in nuclear attribution research often turn to the international forensic science community for technical

The Nuclear Smuggling International Technical Working Group, formed in 1995, works closely with the International Atomic Energy Agency to provide assistance to nuclear forensic scientists around the world. In 2004, the group, which included participants from Lawrence Livermore, met in Cadarache, France, to discuss recent progress in countering the illicit trafficking of nuclear materials.

assistance. In 1995, Niemeyer and Lothar Koch, former division leader at the Institute for Transuranium Elements in Karlsruhe, Germany, started the Nuclear Smuggling International Technical Working Group (ITWG). Experts from 28 countries meet once each year to work on issues concerning illicit trafficking of nuclear materials. The group's objectives include developing protocols for collecting evidence, prioritizing techniques for forensic analyses of nuclear and associated nonnuclear samples, conducting interlaboratory forensic exercises, and developing forensic databanks to assist in interpretation.

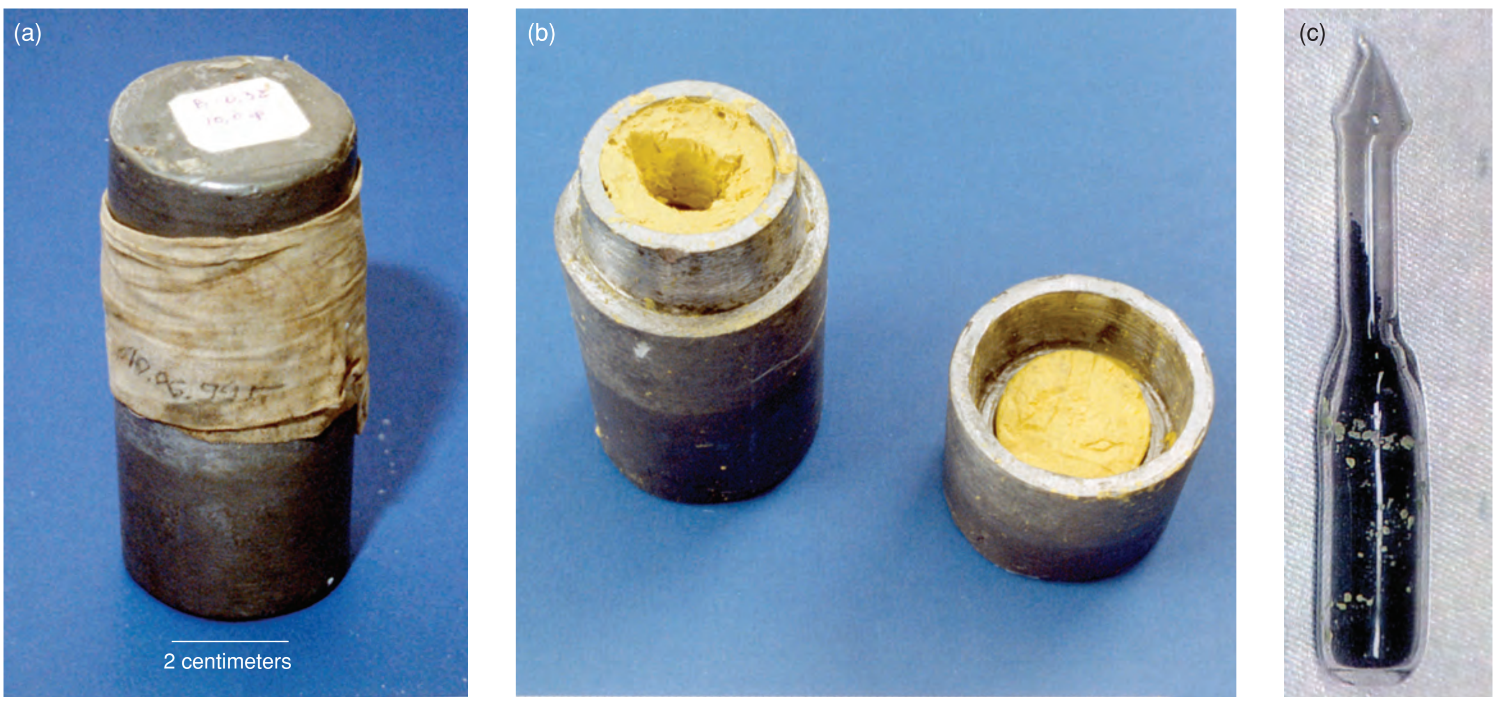
"We want the working group to be a clearinghouse for scientific information in the nuclear forensic field," says Livermore geochemist Dave Smith. ITWG works closely with the International Atomic Energy Agency (IAEA) to provide requesting countries with forensic analyses and support. In 2004, ITWG organized the International Nuclear Forensic Laboratories to establish guidelines for best practices, conduct international exercises, promote research and development, publish reports, and provide point-of-contact assistance.

Countries possessing the equipment necessary to conduct forensic analyses, such as the United Kingdom, France, or Germany, perform their own analyses if nuclear material is intercepted within their borders. Countries without the necessary equipment, for example, many of the smaller nations in Eastern Europe, usually turn to the U.S. for nuclear attribution assistance.

For example, in May 1999, Bulgarian customs officers detained a man who had hidden a 2.4-kilogram lead container in the trunk of his car. Documents found on the suspect described the material as 99.99 percent uranium-235. Inside the container was a glass ampoule filled with several grams of fine black powder. The ampoule was wrapped in paper and cushioned by yellow wax. (See the figure below.) The U.S. Department of State arranged for the National Academy of Sciences in Sofia, Bulgaria, to send the container to Livermore for analyses. The results indicated that the material originated from Eastern Europe.

Nuclear Tracing, Step by Step

Part of the protocol for handling samples sent to the FSC is to set up and maintain a chain-of-custody record. The FSC provides an important link between Livermore's nuclear scientists and federal and state law enforcement agencies. Established in 1991, the center supports DOE in verifying compliance with international treaties, and in 1998, FSC researchers developed methods to help verify the safety of weapons in the U.S.



(a) A lead container shielding an ampoule filled with uranium was seized at the Bulgarian border in 1999 and sent to Livermore for analysis. (b) The interior of the container was lined with yellow wax, which was used to cushion the nuclear material. (c) The glass ampoule contained almost 4 grams of highly enriched uranium oxide.

nuclear stockpile. The team has also assisted federal, state, and local law enforcement on a wide range of cases, including the 1993 World Trade Center bombing and Unabomber investigations.

"The best way to test the techniques we use is to work on real cases," says Livermore chemist Pat Grant, who is the FSC deputy director. "They help us improve our methods and sometimes lead us to develop new techniques."

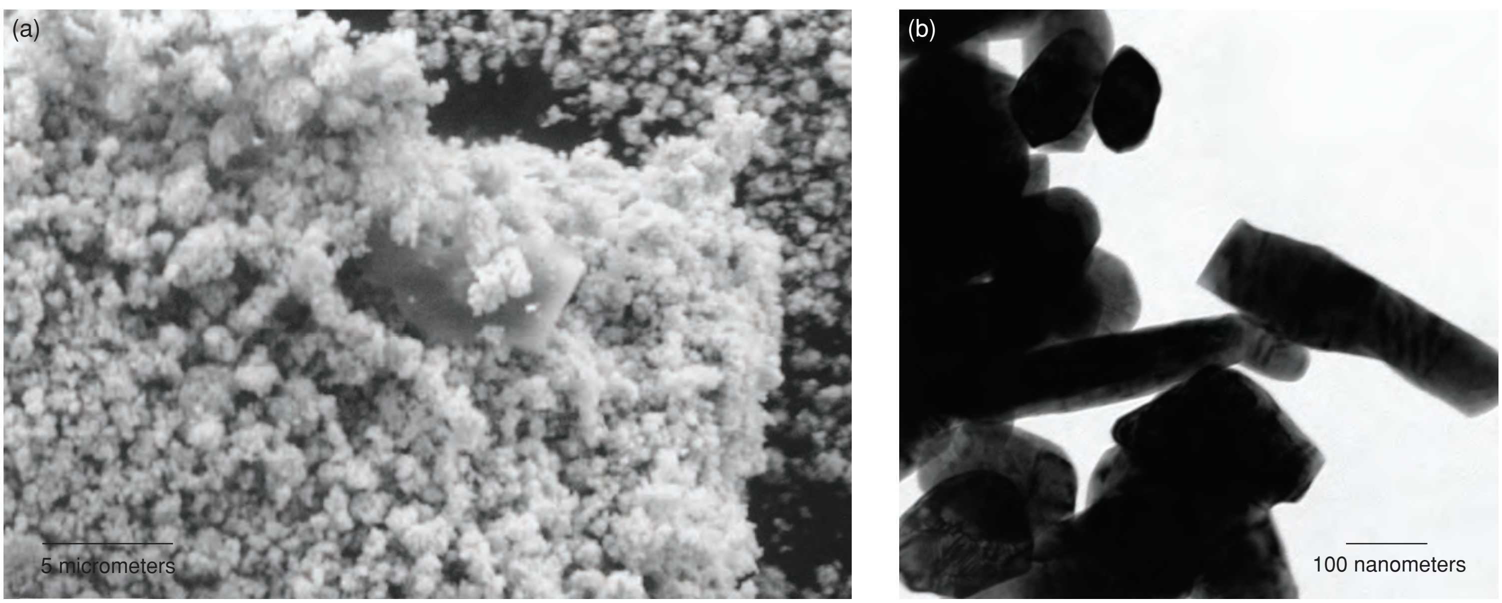
Livermore has had a memorandum of understanding in place with the Federal Bureau of Investigation since 1998 to assist the bureau in combating terrorism. One FSC project develops methods to ensure the integrity of conventional forensic evidence should a dirty bomb be detonated. Residue from such an explosion would contain signatures that might provide important clues to a material's origin. Signatures of a given nuclear or radiologic material include the physical, chemical, and isotopic characteristics that distinguish it from other nuclear or radiological materials. They enable researchers to identify the processes used to create a material. After a detonation, however, hair, fibers, and other evidentiary material near the blast would become contaminated with radioactive material. The challenge for scientists is to preserve the conventional evidence while separating out any radioactive contaminants.

FSC scientists have learned that analyzing the materials accompanying a radioactive sample is as important as characterizing the sample. These so-called route materials—such as containers, fingerprints, fibers, and pollen—provide attribution details about who has handled a sample or the path it has traveled. In the Bulgarian seizure, for example, Livermore scientists used FTIR to confirm that the yellow wax was paraffin. XRF results indicated the yellow coloring was barium chromate, an additive rarely used in Western countries because of environmental concerns but commonly used in Brazil, China, India, and Eastern Europe. Optical microscopy of the paper surrounding the ampoule and the label on the container showed that both of these were a mixture of hardwood and softwood tree fibers commonly found in Eastern Europe.

Tools of the Trade

The FSC works closely with Livermore's Chemistry and Materials Science (CMS) Directorate, which supports a vast array of instruments that researchers can use to build a physical, chemical, and isotopic profile of a material sample. Two tools commonly used in nuclear forensic work are the scanning electron microscope and the transmission electron microscope, which can provide detailed images at resolutions better than 6 and 0.5 nanometers, respectively. Such high-resolution images allow researchers to study the microstructure and chemical composition of individual nanometer-size particles. (See the figure below.)

Because a powdered sample can contain material with different shapes, sizes, and textures, imaging tools must completely characterize a sample while ensuring that important signatures can be recovered from individual components. This step is an essential prerequisite to chemical and isotopic characterization, where components are separated for individual analysis. Moody, who performs radiochemical



(a) This high-resolution image was taken with a scanning electron microscope. The smooth-surfaced, angular object in the center is a shard of glass from an ampoule that contained uranium oxide. (b) The sample was also analyzed with transmission electron microscopy, allowing researchers to study the material's microstructure.

analyses on nuclear samples, relies on such characterization results to help determine which chemicals are needed to break each sample down into a solution for age dating. Chemical analysis reveals the material's exact chemical composition or the association of unique molecular components.

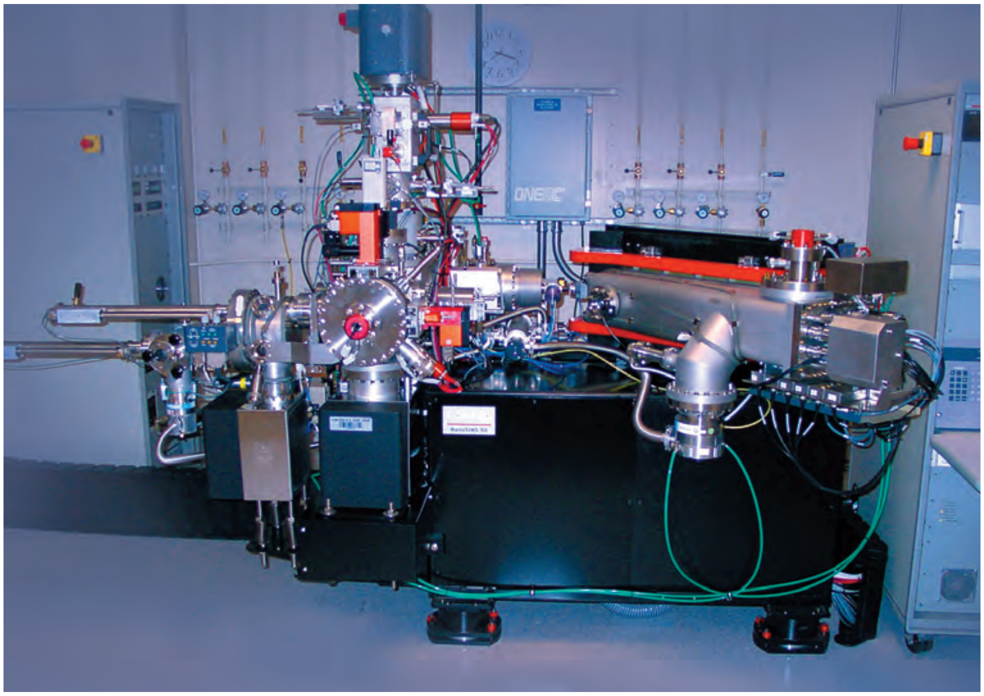
For example, electron microscopy and x-ray diffraction showed the Bulgarian sample to be uranium oxide. Uranium oxide comes in many forms, each of which can be found at various points in the uranium fuel cycle. Trace elements and organic compounds associated with the nuclear material are also important indicators of a material's history.

Another tool widely used in nuclear forensic analysis is the mass spectrometer. In mass spectrometry, a sample is converted into positively and negatively charged ions. The ions are then separated according to their mass-to-charge ratios, and the intensities of the separated ion beams are measured. The secondary ion mass spectrometer (SIMS) can be used as both a microscope and a microprobe. At present, it is the only technique that can perform sensitive elemental and isotopic analysis with submicrometer spatial resolution. Results can be obtained from a specimen as small as a few picograms (10^{-12} grams), about one-millionth the mass of a grain of sand.

The Laboratory's NanoSIMS (shown in the bottom right photograph) is capable of nanometer-scale resolution. Lawrence Livermore is the only national laboratory with this spectrometer, which can also be applied to biological materials analysis, microbial mineralization processes, molecular targeting for cancer therapy, and cosmochemistry research.

The FSC also uses mass spectrometry to analyze the chemistry of route materials. Gas chromatography–mass spectrometry (GC/MS) is useful for measuring trace organic constituents in bulk samples and can analyze samples as small as a grain of salt. In GC/MS, a sample is injected into the end of a column through which gas is flowing. When the sample is heated, it

Livermore nuclear chemist Ken Moody performs forensic radiochemical analysis on samples inside a glovebox. The procedures for working with radioactive samples ensure a safe working environment and maintain the integrity of the samples.



Livermore's newest secondary ion mass spectrometer, called NanoSIMS, can perform ultrasensitive elemental and isotopic analyses at nanometer-scale resolution.

vaporizes into an aerosol of the sample's chemical components. Because chemicals have different vapor pressures and chemical affinities, each component migrates down the column at a different rate. After the components exit the column, they are bombarded with an electron beam, which causes the molecules to break apart into fragment ions and produces a material fingerprint that identifies the compound.

Cataloging the Results

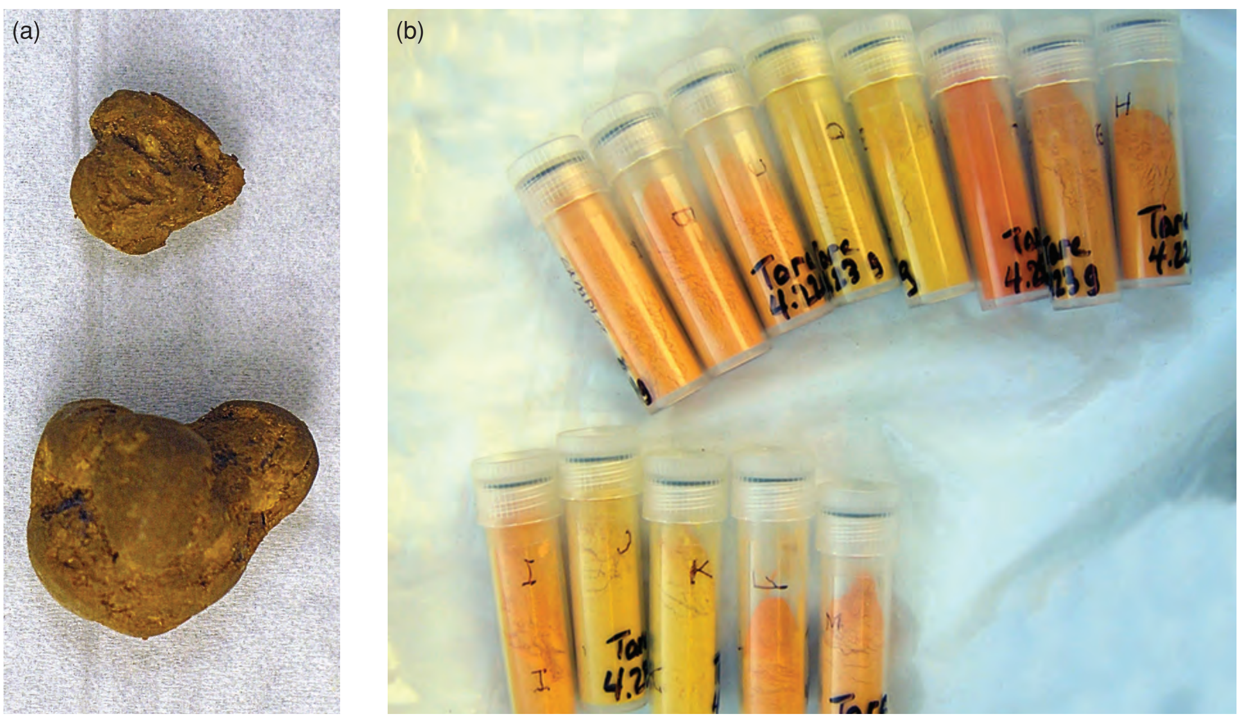
The complete analyses of the Bulgarian sample revealed that it was 73 percent uranium-235 and 12 percent uranium-236, consistent with material that had been recycled from very highly enriched nuclear reactor fuel. Although the amount of HEU confiscated was far short of the quantity needed to fashion a crude bomb, the level of enrichment placed the material in the weapons-grade category.

This incident underscores the security concerns involved in operating commercial and research nuclear reactors. Commercial reactors store large quantities of irradiated nuclear fuel in cooling ponds exposed to the open air. Research reactors often lack containment structures and exclusion zones, and they may be located on university campuses or in other densely populated areas. According to a recent IAEA report, about 130 research reactors in 40 countries operate on weapons-usable HEU.

Nations with nuclear capabilities are beginning to share information about their nuclear processes and materials. Validating the signatures, measurements, and interpretive tools is an important part of building on the Laboratory's nuclear attribution capabilities. Progress in this area requires what the Livermore team calls knowledge management. To compare a sample's signature with known signatures from nuclear production, reprocessing, manufacturing, and storage, researchers must first assemble a library of nuclear materials of known origin. The Livermore team is building its library with the help of Westinghouse and other domestic nuclear fuel fabricators by obtaining samples and data to serve as standards.

Knowledge management also includes determining the best ways to archive and retrieve information, especially during emergencies. According to Smith, knowledge management is as important as analysis capabilities, and it is an area of nuclear attribution that needs much work. To help Livermore improve its capabilities in this area, a nuclear engineer recently joined the team to manage a new attribution database of nuclear signatures.

The database approach will be useful in addressing all WMD issues. Hutcheon explains, "In cases involving potential WMD threats, we are addressing the same questions: How was the sample developed? Where did it originate? How old is it, and what is its intended use? We also want to be able to identify and correct any failures in our tracking system."



(a) A sample of uranium oxide is shown before its chemical composition has been analyzed. (b) A suite of known uranium oxide samples are used in comparison studies.

The Laboratory is involved in knowledge management activities across the spectrum of nuclear, chemical, and biological threats. For example, in 2004, Livermore established the Biodefense Knowledge Center to provide DHS with on-call technical assistance in the fight against bioterrorism. The center draws on about 75 researchers based at four national laboratories—Oak Ridge, Pacific Northwest, Sandia, and Lawrence Livermore.

According to Smith, ITWG also plans to develop databases as an international resource for nuclear forensic work. Elements of such databases already exist, but most stored data are collected for environmental impact analyses, weapons performance testing, or other purposes. Although the information may be valuable for nuclear forensic analysis, no country is likely to divulge all of the information in its databases. Thus, ITWG's goal is to serve as an intermediary, where countries can confirm results or fill in missing pieces of information, if presented with details of a suspicious material.

Programs to Safeguard Material

Livermore researchers are also contributing to projects to help Russia secure, consolidate, and eliminate fissile materials. (See *S&TR,* January/February 2005, pp. 14–21.) In May 2004, then Secretary of Energy Spencer Abraham launched the Global Threat Reduction Initiative (GTRI), with the goal of repatriating all Soviet-origin HEU fuel to Russia by the end of 2005. DOE plans to work with Russia to repatriate all Soviet-origin spent nuclear fuel by 2010 and all spent research reactor fuel of U.S. origin by 2015. The U.S. government has announced plans to dedicate more than $450 million to the GTRI, and an organization has been created within the National Nuclear Security Administration to implement this and other GTRI tasks. A complementary effort has been the construction of the Mayak Fissile Material Storage Facility at Ozersk, Russia, a program sponsored by the Department of Defense. When completed, the facility will house and secure 50 tons of Russian weapons-grade plutonium.

Other Laboratory research supports DHS in its efforts to screen for radioactive materials at the nation's border security checkpoints. One area of concern is that radioactive materials could be hidden on ships destined for U.S. ports. To address this problem, DHS has funded the Container Security Initiative, which focuses on securing the ports that handle nearly 90 percent of the world's shipping. One Livermore project in support of this initiative combines the Laboratory's expertise in radiation science and detection to quickly screen cargo containers. (See *S&TR*, May 2004, pp. 12–15.)

Tomorrow's Nuclear Scientists

At a time when the nation has a critical need for nuclear forensic scientists, the number of students at U.S. universities who are pursuing nuclear science degrees is declining. A primary reason for this reduced focus is the declining nuclear power industry and the lack of job opportunities for graduates. The country's research reactors are being closed, and new commercial nuclear reactors are not being built. Livermore's nuclear forensic team wants to reverse this educational trend and is working with the Laboratory's Glenn T. Seaborg Institute, which is part of CMS, to identify and attract the next generation of nuclear scientists.

Annie Kersting, the institute's director, says, "We see nuclear attribution as a new career avenue for students. Working with our equipment is an attractive option for students interested in nuclear science and will help the Laboratory to rebuild the nuclear chemistry expertise we had in the days of underground testing."

Tomorrow's generation of weapons scientists face many new and unexpected challenges in addressing the world's nuclear threat. As Livermore continues to ensure the performance and safety of the U.S. nuclear stockpile—a vital part of its national security mission—nuclear forensic scientists will continue to develop tools and attribution processes to trace illicit nuclear materials to their sources.

—Gabriele Rennie

Key Words: Forensic Science Center (FSC), gas chromatography/mass spectrometry (GC/MS), nano-secondary ion mass spectrometer (NanoSIMS), nuclear forensic analysis, Nuclear Smuggling International Technical Working Group (ITWG), scanning electron microscope, transmission electron microscope.

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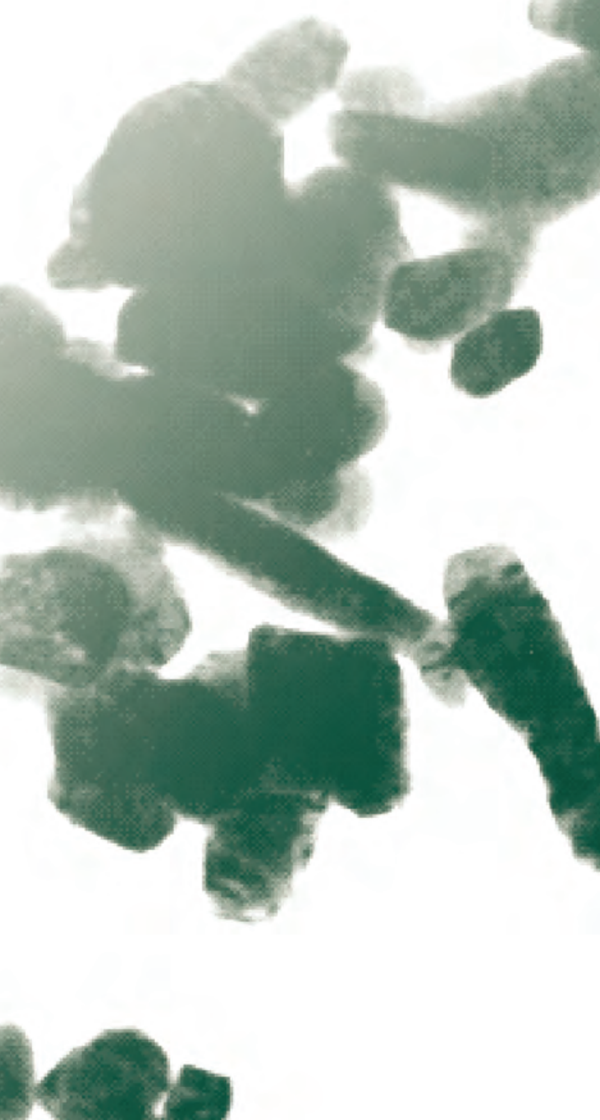


Looking at Earth in Action

Surface outcropping of the San Andreas Fault near Parkfield, California.

EXPERIMENTAL geophysicists at Livermore are tackling diverse challenges such as the storage of nuclear wastes, discovery of new energy sources, mitigation of greenhouse effects, and better understanding of nuclear weapons. They set up experiments in the laboratory so they can examine how specific environments alter material properties. According to Brian Bonner, who leads the Laboratory's Experimental Geophysics Group, much of what these scientists do is "indoor geophysics," bringing Earth into the laboratory.

"Natural systems are so complex that we can often learn more about the physical processes in the laboratory—where we can isolate the controlling variables and study the processes systematically," says Bonner. In this way, researchers can better understand the geophysical processes occurring deep within Earth's subsurface and across the vast expanses of its surface.

Indoor Geophysics

Much of the group's work involves subjecting materials to extreme temperatures and pressures. Earth and the other planets in our solar system are places of extreme conditions: Earth's interior can reach pressures of more than 350 gigapascals and temperatures of 6,000 kelvins. (Normal surface pressure at sea level is 1 atmosphere, or about one-ten-thousandth of a gigapascal.)

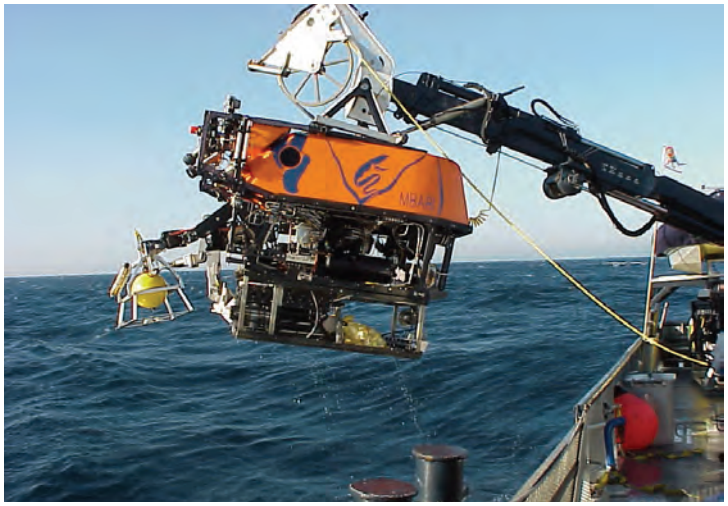
Because these extreme conditions are similar to those produced by nuclear detonations and other high explosives, the geophysicists also contribute their expertise to projects in support of Livermore's stockpile stewardship mission. In one of the Laboratory's early efforts to develop a science-based stockpile stewardship program in the absence of nuclear testing, Livermore geophysicist Jagan Akella used the diamond anvil cell, which was developed to study molten iron at Earth's core, to examine the melting of metals used in nuclear weapons. (See *S&TR*, March 1996, pp. 17–27.)

No Fault Zone

The group is also working on projects that involve traditional applications of geophysics, such as the dynamics of earthquakes. Jeff Roberts, a Livermore experimental geophysicist, recently collaborated with Stephen Park and colleagues from the Institute of Geophysics and Planetary Physics at the University of California at Riverside to study the San Andreas Fault near Parkfield, California. Parkfield is a small town in central California, halfway between Los Angeles and San Francisco. Earth scientists have studied this area for decades because earthquakes occur frequently in this region of the fault.

The Parkfield team investigated an area just west of the visible surface trace of the fault and extending 3 kilometers below the surface. Data recordings from this region indicated anomalous electrical conductivity, which many geophysicists attribute to the fractured rock being saturated with brine. Laboratory experiments indicate that the resistivities of rocks in this anomalous zone were comparable to the resistivities of sedimentary rock samples taken along the eastern border of the fault.

One interpretation of this finding is that the anomalous conductivity is caused by a plunging syncline—a trough of sedimentary rock—



Livermore geophysicists and researchers from the Monterey Bay Aquarium Research Institute are measuring the dissolution kinetics of carbon dioxide and methane hydrate at sea-bottom conditions. Here, a pressure vessel containing hydrate samples is being lowered to the experimental site—the underwater Monterey Canyon, about 15 kilometers off the coast of central California.

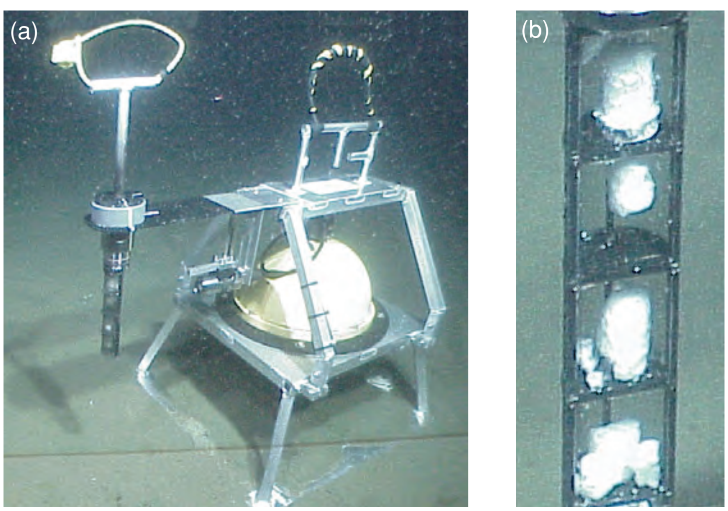
adjacent to the fault. The researchers conducted further experiments in the region to determine the exact location of the syncline and compared those results with other data. From this analysis, the team proposed that part of the San Andreas Fault may actually lie about 1 kilometer west of its mapped location. This proposal is controversial, and further research will be needed to confirm or disprove the revised location of the fault.

Under the Sea

Other members of the Experimental Geophysics Group are studying the changing environment under the sea floor, where gas hydrates—crystalline solids that look like water ice—lay trapped in marine sediments. According to Livermore geophysicist William Durham, the amount of carbon bound in gas hydrates worldwide is estimated to be twice the amount of carbon found in all known fossil fuels on Earth. (See *S&TR*, March 1999, pp. 20–22.)

"Not only are gas hydrates possible alternative carbon fuel sources," says Durham, "but they also could be important in mitigating global warming." One possibility being explored is using carbon dioxide hydrate as a means of removing carbon dioxide from the atmosphere.

To examine the stability of these hydrates, Durham's team collaborated with researchers from the Monterey Bay Aquarium Research Institute to measure the dissolution kinetics of carbon dioxide and methane hydrate at sea-bottom conditions. For this experiment, which received funding from Livermore's Laboratory Directed Research and Development Program, researchers grew cylindrical samples of pure methane and carbon dioxide hydrate in the laboratory by combining either cold pressurized methane gas or pressurized liquid carbon dioxide with water ice.



(a) The pressure vessel is delivered to the sea floor—more than 1,000 meters deep. Once the vessel is opened, (b) samples of pure methane hydrate and carbon dioxide hydrate are recorded by an underwater video system. Using data from the recording, researchers measure the shrinkage rates of the samples to calculate how quickly the hydrates dissolved.

They then transported the hydrates to the experimental site—the underwater Monterey Canyon, which lies about 15 kilometers off the coast of central California in Monterey Bay. The samples were placed in a pressure vessel and delivered to the sea floor—more than 1,000 meters deep. Once the vessel was in position, it was opened in view of a time-programmable underwater video system. The images captured by the camera allowed the team to measure the shrinkage rates of the samples and thus calculate how quickly the hydrates dissolved. The carbon dioxide hydrate dissolved completely in 4 to 6 hours. The methane hydrate was far more stable at sea-floor conditions. In fact, these samples had not completely dissolved when the researchers returned the next day.

Understanding the stability of hydrate deposits is relevant to several research areas. For example, astrophysicists are interested in methane hydrate because it is a building material of the outer planets in our solar system. Methane hydrate deposits also occur on Earth near conventional oil deposits. Drilling companies need accurate locations of hydrate deposits because drilling through these pockets could lead to catastrophic events, such as undersea landslides, explosions of freed gas, or even, according to Durham, tsunamis.

Bringing It All Together

When Livermore's Experimental Geophysics Group looks beneath Earth's crust, under its sea floors, and into the sedimentary rock formations at its surface, the research encompasses much more than geology. The group's work touches national security, environmental science, the discovery of new energy sources, and even astrophysics.

"This group faces an evolving series of interdisciplinary challenges, and our broad collective expertise helps us meet them," says Bonner. "We have geologists, people with physics and chemistry backgrounds, an engineer or two, and even one group member whose first degree was in economics. When we don't have the right talent in house, we form collaborations inside and outside the Laboratory. Our experience is that adaptable, versatile people do well at finding solutions to crosscutting problems."

—Maurina S. Sherman

Key Words: gas hydrates, geophysics, ice physics, methane hydrate, San Andreas Fault.

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Gamma-Ray Bursts Shower the Universe with Metals

Gamma-ray bursts may be the "birth cry" of a black hole.

ACCORDING to the results from a Livermore computer model, some of the small change jingling in your pocket contains zinc and copper created in massive gamma-ray bursts (GRBs) that rank as the most impressive light shows in the universe.

Livermore astrophysicist Jason Pruet and his colleagues Rebecca Surman and Gail McLaughlin from North Carolina State University (NCSU) reported on their calculations in the February 20, 2004, issue of *Astrophysical Journal Letters*. They found that GRBs from black holes surrounded by a disk of dense, hot plasma may have contributed heavily to the galactic inventory of elements such as calcium, scandium, titanium, zinc, and copper. "A typical GRB of this kind briefly outshines all the stars in millions of galaxies combined," says Pruet. "Plus it makes about 100 times as much of some common elements as an ordinary supernova."

Star Light, Star Bright

Gamma-ray bursts were discovered during the Cold War–era research to develop space technologies for monitoring arms-control agreements. Between 1963 and 1970, the U.S. launched 12 Vela satellites to search for the x and gamma rays that would indicate a nuclear explosion in the upper atmosphere. These satellites detected several intense but fleeting flashes of gamma rays. The rays, however, were not from a nuclear test. They originated somewhere deep in space, but where—and what caused them—remained a mystery.

"A heated debate followed," says Pruet. "Many scientists believed the bursts originated in our galaxy. If they were peppered throughout the universe, these events would be incredibly energetic." More than two decades passed before satellite technology could provide the measurement sensitivity needed to resolve this mystery. Then in 1991, when the Compton Gamma Ray Observatory (CGRO) satellite was launched, scientists began to get meaningful answers to their questions. During the satellite's 9 years on the job, it detected more than 2,600 GRBs flashing and fading in seconds or minutes, too brief to aim a telescope for follow-up observations.

The CGRO data indicated that bursts appeared from random directions in the sky. This finding led many astronomers to believe that GRBs occurred outside the Milky Way in other galaxies. Unfortunately, the CGRO satellite was not sensitive enough to pinpoint which specific galaxies hosted these spectacular explosions. Each event could only be localized to within an area large enough to contain several thousand galaxies.

The Dutch-Italian BeppoSAX x-ray astronomical satellite, which was launched in 1996, solved this sensitivity problem. By correlating x-ray data from BeppoSAX with data from ground-based observatories, astronomers could finally verify that GRBs are indeed deep in space—some more than 8 billion light years away. Thus, observed GRBs occurred in distant reaches of the universe far, far back in time.

Data from BeppoSAX proved that GRBs are not only extragalactic but also the most energetic events in the universe. If GRBs are isotropic, emitting energy in all directions equally, then the energy from some bursts would approach one solar rest mass—the total energy obtained if the Sun is entirely converted to energy. Observations in the last few years indicate that GRBs are not isotropic but, instead, are beamed to about 1 percent of the sky. The total energy emitted is still enormous, but more plausible.

The BeppoSAX data have helped scientists understand the energy of GRBs. Their next challenge was to determine what causes the powerful bursts. "Several hundred papers appeared advancing different ideas," says Pruet. "For example, some proposed that GRBs are caused by 'puffy' neutron stars or evaporating black holes. Other researchers suggested the GRBs are supermassive stars that are the grandparents of today's stars."

Today, the leading model for explaining these mysterious events is the collapsar, or collapsing star, model proposed by Stan Woosley, a professor of astronomy and astrophysics at the University of California at Santa Cruz (UCSC) and a longtime Livermore collaborator. According to the collapsar model, a GRB arises when a dying rotating star is too massive to successfully explode as a supernova. Instead, the star collapses into a black hole surrounded by a dense accretion disk, which spirals into the black hole like water flowing down a drain. The GRB—the "birth cry" of the black hole—is produced by gravitational energy liberated as disk material falls into the black hole.

Pennies from Heaven

Another interesting twist to the mystery emerged a few years ago. Data show that a fraction of GRBs emits light with characteristics similar to emissions from ordinary supernovae. The supernovalike light curves indicate that these extremely energetic explosions are spewing out about one-half of a solar mass of radioactive nickel at thousands of kilometers per second. "A couple of theories have been proposed to explain how this nickel is created," says Pruet.

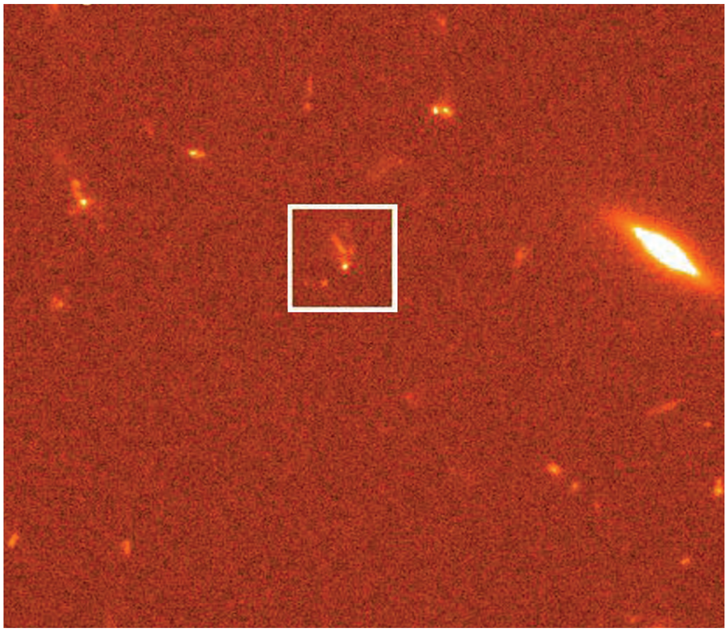
One proposal is that the nickel is created from "explosive burning," much like what happens in ordinary supernovae. In explosive burning, a violent shock traversing the stellar mantle heats nuclei and rips them apart. As the nucleons cool, they recombine to form radioactive nickel and progenitors of other common elements. "However," says Pruet, "simulations of exploding stars show that nickel production through explosive burning in a collapsar is unlikely."

Another possibility, first suggested by Woosley and his colleague Andrew MacFadyen, is that the nickel originates from a wind blown off the accretion disk. "The cold matter making up the star's inner layers is drawn into the disk by the enormous pull of the black hole," Pruet says. "As the matter moves closer to the black hole, it becomes hotter and denser, dissociating into its nuclear components—neutrons and protons. One might guess that this disk material is doomed; however, about half of the accretion disk escapes in a viscous wind before it is consumed by the black hole. New nuclei, including iron, are synthesized as this wind cools and the radioactive nickel decays."

Pruet and his colleagues are also investigating whether collapsars might be the sources of other elements as well. Livermore's work on this project is funded through a grant Woosley received from the Department of Energy's (DOE's) Program for Scientific Discovery through Advanced Computing. The NCSU team received DOE funding by winning an Outstanding Junior Investigator Award.

"Rather than develop a theory describing the disk wind, we began with the assumption that a wind is responsible for the observed abundance of nickel," says Pruet. "Just using this simple assumption allows us to calculate the nucleosynthesis of other elements in the wind." The team then modeled the outflow and used large nuclear reaction network calculations to examine disk-wind nucleosynthesis. These reaction codes, maintained by Livermore scientist Rob Hoffman, describe the "burning" of nuclei from neutrons and protons to much heavier elements.

The researchers found that GRBs also produce smaller but still enormous quantities of such everyday elements as zinc, titanium,



Gamma-ray bursts, such as the one in the box, not only outshine all the stars in their own galaxies but also contribute to the galactic inventory of many common elements.

copper, and scandium. Only a few stars in every hundred are expected to produce GRBs when they die. However, according to the team's calculations, these rare events probably account for as much of some elements as do all other stellar explosions combined. To put this finding in perspective, says Pruet, consider that a modern penny is 97.5 percent zinc and 2.5 percent copper. Then the raw material for about 20 pennies in every dollar may have narrowly escaped being eaten by a black hole.

More Answers on the Horizon

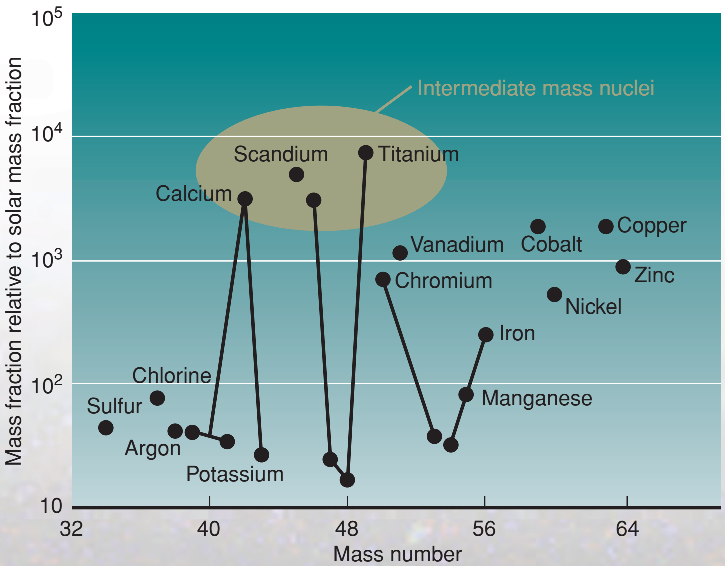
This research may help explain other curious phenomena as well. For example, some observations indicate that x-ray emission lines may be associated with collapsars, and some scientists speculate that those lines come from iron. Others have suggested that the emission lines are from nickel, perhaps being ejected at high velocity behind a jet emitted from the poles of the collapsar. Both the existence and source of these lines are debated.

"If a disk wind is producing radioactive nickel," says Pruet, "then its decay product, iron, is by far the most abundantly produced element in the wind. The second most abundant element—generally zinc—is much less, 5 percent or less of the total elements produced." If the radioactive nickel, which lives for about a week, is responsible for the x-ray emission lines, then scientists should find an initial strong line or lines from nickel with much weaker lines from other elements such as zinc.

Further research on GRBs may also help scientists understand the history of element production in the Milky Way galaxy by providing a record of events, much like fossils provide a record of geologic events on Earth. “If these bursts make sizable contributions to the inventory of scandium, titanium, copper, and zinc in the universe, we should be able to read the history of GRBs in the nuclear abundance patterns of stars,” says Pruet. “There’s likely a signature of past GRBs in stars. For instance, as a star explodes, the mass is mixed in the galaxy. When the mass collapses inward, another star is born. Thus, if we find a star showing a lot of scandium, we might be able to say that, in the past, a GRB occurred near this star’s birthplace.”

By examining material expelled from black holes near GRBs, scientists may also gain insights into where the heavy elements—gold, silver, plutonium, and uranium—were first formed. Synthesizing these elements requires neutron-rich conditions, and if the team’s calculations are right, the inner area of black-hole accretion disks provides such a source. The answer to this question and others may indeed be blowing in the wind.

—Ann Parker



Calculations for nucleosynthesis in a collapsar wind indicated that collapsars and their attendant gamma-ray bursts could be the source of elements such as scandium, titanium, zinc, and copper.

Key Words: accretion disk, black hole, collapsar model, copper, disk wind, gamma-ray burst (GRB), neutron star, nickel, nuclear reaction network, nucleosynthesis, scandium, supernova, zinc.

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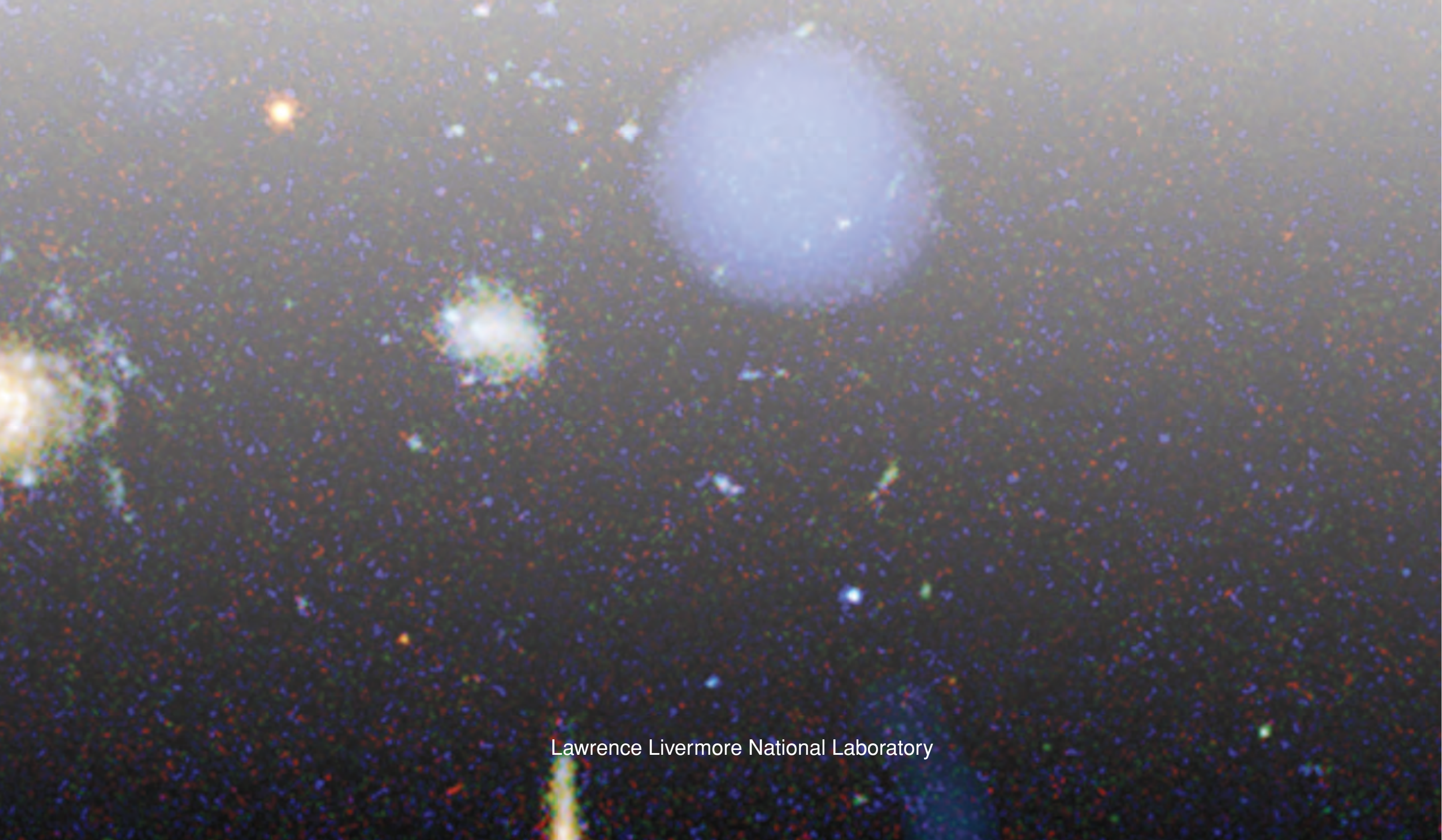

Patents and Awards

Each month in this space, we report on the patents issued to and/or the awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory.

Patents

Universally Oriented Renewable Liquid Mirror
Dmitri D. Ryutov, Arthur Toor
U.S. Patent 6,764,187 B2
July 20, 2004
A liquid mirror that can be universally oriented is made by connecting a liquid and a penetrable unit.

Using Impedance Measurements for Detecting Pathogens Trapped in an Electric Field
Robin R. Miles
U.S. Patent 6,764,583 B2
July 20, 2004
Impedance measurements between the electrodes in an electric field are used to detect pathogens trapped in the field. When particles are trapped in an electric field by the dielectrophoretic force, the impedance between the electrodes can be changed by changing the dielectric material between the electrodes. Therefore, the degree of particle trapping can be determined by measuring the impedance. This measurement is used to determine whether a sufficient amount of pathogen has been collected to further analyze or possibly identify the pathogen.

Hydraulically Amplified PZT MEMS Actuator
Robin R. Miles
U.S. Patent 6,811,133 B2
November 2, 2004
In this hydraulically amplified microelectromechanical systems (MEMS) actuator, a piece of piezoelectric material or stacked piezo bimorph is bonded or deposited as a thin film and then connected to a primary membrane. A reservoir containing fluid is also connected to the primary membrane, and a second membrane is connected to the reservoir. Energizing the piezoelectric material causes the material to bow, which causes the primary membrane to move. This movement transmits a force to the liquid in the reservoir, which causes the next membrane to move. Movement of the membrane results in an operating actuator.

Method for Making Thick and/or Thin Film
Ai Quoc Pham, Robert S. Glass
U.S. Patent 6,811,741 B2
November 2, 2004
This method for making low-cost thick or thin films is similar to the conventional tape-casting techniques, but it is more flexible and versatile. A slip (solution) of the desired material is prepared. Solvents such as ethanol and an appropriate dispersant are included in the solution to prevent agglomeration. An atomizer then sprays the slip in a fine mist onto a substrate. When the mist hits the substrate, the solvent evaporates, leaving a green tape that contains the powder and other additives. This tape may be punctured, cut, and heated for the desired application. Tape thickness can vary from about 1 micrometer upward.

Flexible Interconnects for Fuel Cell Stacks
David J. Lenz, Brandon W. Chung, Ai Quoc Pham
U.S. Patent 6,815,116 B2
November 9, 2004
This interconnect facilitates electrical connection and mechanical support for fuel-cell stacks with minimal mechanical stress. The interconnects are flexible and provide mechanically robust fuel-cell stacks with higher stack performance at lower cost. The rigid ribs used in previous interconnects are replaced with flexible “fingers,” or contact pads, that will accommodate the imperfect flatness of the ceramic fuel cells. The mechanical stress of stacked fuel cells will be smaller because of the fingers’ flexibility. The interconnects can be one- or two-sided.

Fuel Cell Apparatus and Method Thereof
John F. Cooper, Roger Krueger, Nerine Cherepy
U.S. Patent 6,815,105 B2
November 9, 2004
Highly efficient carbon fuels, exemplary embodiments of a high-temperature, molten electrolyte electrochemical cell, can directly convert ash-free carbon fuel to electrical energy. Ash-free, turbostatic carbon particles perform at high efficiencies in certain direct carbon conversion cells.

Inorganic Metal Oxide/Organic Polymer Nanocomposites and Method Thereof
Alexander E. Gash, Joe H. Satcher, Randy Simpson
U.S. Patent 6,818,081 B2
November 16, 2004
This synthetic method for preparing hybrid inorganic–organic energetic nanocomposites uses stable metal in organic salts and organic solvents as well as an organic polymer with good solubility in the solvent system. In addition, fuel metal powders, particularly those that are oxophilic, can be incorporated in the composition. This material has been characterized using thermal techniques, energy-filtered transmission electron microscopy, nitrogen adsorption–desorption methods, and Fourier-transform infrared spectroscopy. According to these characterization results, the organic polymer phase fills the material’s nanopores, providing superb mixing of the component phases in the energetic nanocomposite.

Laser Peening with Fiber Optic Delivery
Herbert W. Friedman, Earl R. Ault, Karl F. Scheibner
U.S. Patent 6,818,854 B2
November 16, 2004
This system uses a laser that produces at least one laser pulse and a laser processing unit to process the workpiece. A fiber-optic cable transmits the laser pulse (or pulses) from the laser to the laser processing unit.

Selectively-Etched Nanochannel Electrophoretic and Electrochemical Devices
Michael P. Surh, William D. Wilson, Troy W. Barbee, Jr., Stephen M. Lane
U.S. Patent 6,818,964 B2
November 16, 2004
Nanochannel electrophoretic and electrochemical devices have selectively etched nanolaminates located in the fluid transport channel. The normally flat surfaces of the nanolaminate, which has exposed conductive (metal) stripes, are selectively etched to form trenches and baffles. These modifications increase the amount of exposed metal to facilitate electrochemical redox reaction or control exposure of the metal surfaces to large analytes. The etched areas variously increase the sensitivity of electrochemical detection devices to low analyte concentrations, improve the plug flow characteristic of the channel, and allow additional discrimination of the colloidal particles during cyclic voltametry.

Method of Forming a Package for MEMS-Based Fuel Cell
Jeffrey D. Morse, Alan F. Jankowski
U.S. Patent 6,821,666 B2
November 23, 2004
This microelectromechanical systems– (MEMS-) based fuel-cell package has seven layers: (1) a subpackage fuel reservoir interface, (2) an anode manifold support, (3) a fuel–anode manifold and resistive heater, (4) a thick-film microporous flow host structure that contains a fuel cell, (5) an air manifold, (6) a cathode manifold support structure, and (7) a cap. Fuel-cell packages with more than one fuel cell are formed by positioning stacks of these layers in series, in parallel, or both. Fuel-cell package materials, such as a molded plastic or a ceramic green tape material, can be patterned, aligned, and stacked to form three-dimensional microfluidic channels. These channels provide electrical feedthroughs from various layers, which are bonded together and mechanically support a MEMS-based miniature fuel cell. The package incorporates resistive heating elements to control the temperature of the fuel-cell stack. The package is fired to form a bond between the layers. Then one or more microporous flow host structures containing fuel cells are inserted within the thick-film microporous flow host structure layer.

Co-Flow Planar SOFC Fuel Cell Stack
Brandon W. Chung, Ai Quoc Pham, Robert S. Glass
U.S. Patent 6,824,910 B2
November 30, 2004
The co-flow, planar solid oxide fuel cell (SOFC) stack has an integral, internal manifold and a casing/holder to separately seal the cell. This construction improves sealing and gas flow and provides for easy manifolding of cell stacks. In addition, the stack construction may improve durability and operation by increasing cell efficiency. The co-flow arrangement can be used in other electrochemical systems requiring gas-proof separation of gases.

Process for Direct Integration of a Thin-Film Silicon p-n Junction Diode with a Magnetic Tunnel Junction
Daniel Toet, Thomas W. Sigmon
U.S. Patent 6,828,180 B2
December 7, 2004
This process directly integrates a thin-film silicon p-n junction diode with a magnetic tunnel junction for use in advanced magnetic random access memory cells for high-performance, nonvolatile memory arrays. Pulsed laser processing is used to fabricate vertical polycrystalline silicon electronic device structures—in particular, p-n junction diodes—on films of metals that have been deposited onto low-temperature substrates, such as ceramics, dielectrics, glass, or polymers. The process preserves the underlayers and structures, such as silicon integrated circuits, onto which the devices are deposited. The process involves the low-temperature deposition of at least one layer of silicon, either in an amorphous or a polycrystalline phase on a metal layer. Dopants may be introduced in the silicon film during or after deposition. The film is then irradiated with short-pulse laser energy, which is efficiently absorbed in the silicon. This process crystallizes the film and simultaneously activates the dopants via ultrafast melting and solidification. The silicon film can be patterned either before or after crystallization.

Transverse Flowing Liquid Kerr Cell for High Average Power Laser Q-Switching and for Direct Modulation of High Power Laser Beams
Brian J. Comaskey
U.S. Patent 6,829,257 B2
December 7, 2004
A fluid flow concept is applied in an optical apparatus to define a high-gain standoff, fast electro-optical Q switch, which is highly impervious to high-average-power optical loads.

Awards

Jerry Lin of Livermore's Defense Technologies Engineering Division has been named a **Fellow** of the **American Society of Mechanical Engineers** (ASME). The fellow grade is the highest elected grade of membership within ASME. Lin was recognized for his pioneering work in computational mechanics, including contact algorithms, mixed time integration, element eigenvalue theorems, and element technologies that have been adopted for use in many finite-element codes.

Physicist **Cherry Murray**, who recently joined the Laboratory as deputy director for Science and Technology, received the **2005 George Pake Prize** from the **American Physical Society** (APS). The George Pake Prize is one of the APS's most distinguished awards. It recognizes and encourages outstanding work by physicists combining original research accomplishments with leadership and development in industry. Murray received the award for fundamental studies in surface and scattering physics and for her previous leadership as senior vice president of Bell Labs Research, Lucent Technologies—in particular, for "overseeing Bell Laboratories at an important time in its history."

Building Networks of Trust through Collaborative Science

Lawrence Livermore scientists are using science- and technology-based cooperative projects as a means of working with foreign colleagues to help curb nuclear smuggling, understand earthquake hazards, prepare for disasters, and prevent massive environmental damage. The focus is on regions of concern for nuclear proliferation, including Central and South Asia and the Middle East. The efforts are spearheaded by Livermore's Proliferation and Terrorism Prevention Program, part of the Nonproliferation, Arms Control, and International Security (NAI) Directorate. Livermore-led collaborative projects are supported by U.S. and European government agencies, the United Nations, the World Bank, and private organizations. The projects bring together scientists in a geographical region to work on technical issues that cross national boundaries. Central Asia projects include efforts to curb smuggling of nuclear materials, prevent uranium tailings from contaminating the environment, and strengthen seismic networks. Projects in the Middle East focus on water, seismic, and radiologic concerns.

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Keith Nakanishi (925) 422-3923 (nakanishi1@llnl.gov).

Tracing the Steps in Nuclear Material Trafficking

Livermore researchers are applying their expertise in nuclear science to the growing field of nuclear forensic analysis. This research will help the U.S. prevent terrorists from acquiring not only nuclear weapons but also the materials that can be used to make such weapons, including fuel for power plants or radioactive materials intended for medical use. Livermore's nuclear forensic activities began in the late 1980s as an outgrowth of work in the nuclear test program, where researchers added chemical and isotopic tracers to a nuclear test device and measured the isotopic composition of the debris produced in the experimental blast. The Laboratory's Forensic Science Center and Chemistry and Materials Science Directorate use an array of equipment to develop physical, chemical, and isotopic profiles of a sample down to the nanometer scale. In 1995, the Nuclear Smuggling International Technical Working Group, involving 28 countries, was established to work on issues surrounding illicit trafficking of nuclear materials. Livermore researchers are contributing to several U.S. programs designed to help Russia secure, consolidate, and eliminate fissile materials. The Laboratory is also working with the U.S. Bureau of Customs and Border Protection to implement technologies at border security checkpoints and ports of call that will help detect illicit nuclear and radioactive materials before they enter the country.

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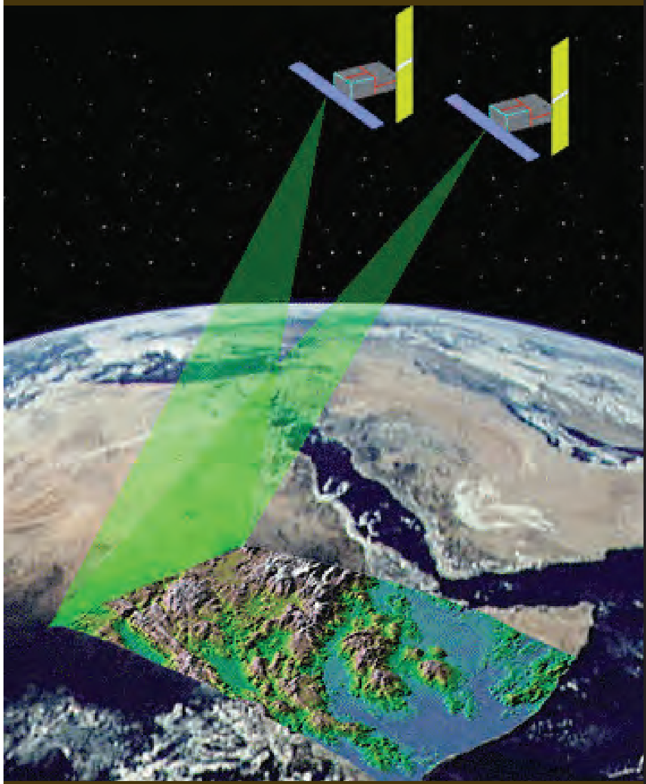
U.S. Government Printing Office: 2005/783-059-10005

Imaging Earth's Subsurface



Satellite radar images are being used to detect clandestine underground nuclear explosions and natural hazards such as earthquakes and tsunamis.

Also in April

• Livermore's Sabbatical Scholars Program is attracting top academic scientists and their students.

• Frogs help Laboratory biologists identify functional elements in the human genome.

• BlueGene/L—the world's most powerful supercomputer—features a highly scalable platform with an innovative design.

Coming Next Month

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